

What is claimed is:

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1 1. The method for simulating dental procedures for training dental students  
2 comprising, in combination, the steps of:  
3 employing a digital computer consisting of a processor and a display device to  
4 display a model of a tooth,  
5 employing said digital computer and display device to display a model of a dental  
6 tool, and  
7 employing a haptic interface device that is manually moveable by a dental student  
8 and coupled to said digital computer to move the said model of a dental tool with respect  
9 to said model of a tooth to haptically simulate a dental procedure.

1 2. The method set forth in claim 1 wherein said dental tool is a pick having a  
2 handle and wherein said haptic interface includes a stylus movable by said dental student  
3 to simulate the motion of said handle.

1 3. The method set forth in claim 1 wherein said dental tool is a drill having a  
2 handle and wherein said haptic interface includes a stylus movable by said dental student  
3 to simulate the motion of said handle.

1 4. The method set forth in claim 1 wherein said dental tool is an amalgam carrier  
2 having a handle and wherein said haptic interface includes a stylus movable by said  
3 dental student to simulate the motion of said handle.

1 5. The method set forth in claim 1 wherein said dental tool is a carver having a  
2 handle and wherein said haptic interface includes a stylus movable by said dental student  
3 to simulate the motion of said handle.

1 6. The method set forth in claim 1 wherein said model of a dental tool is selected  
2 by said student from a plurality of available dental tools, each of which has a handle, and  
3 wherein said haptic interface includes a stylus movable by said dental student to simulate  
4 the motion of the handle of each of said tools.

1 7. The method set forth in claim 6 wherein said plurality of dental tools  
2 comprises at least a pick, a carver, and a drill.

1 8. The method set forth in claim 6 wherein said plurality of dental tools  
2 comprises at least a pick, a carver, a drill and an amalgam carrier.

1 9. The method set forth in claim 1 wherein said display device renders said  
2 model of a tooth and said model of a dental tool in a stereoscopic three dimensional  
3 display.

1 10. The method set forth in claim 1 wherein said a haptic interface device that is  
2 manually moveable by a dental student includes a moveable stylus that is moveable in at  
3 least three degrees of freedom.

1 11. The method set forth in claim 1 wherein said display device renders said  
2 model of a tooth volumetrically as a solid object consisting of a collection of volume  
3 elements.

1 12. The method set forth in claim 12 wherein said model of a tooth is subdivided  
2 into different regions simulating different materials said materials including enamel,  
3 dentin and pulp.

1 13. The method as set forth in claim 1 wherein said model of a dental tool  
2 represents a drill, said method further including the step of removing portions of said  
3 model of a tooth that are intersected by said drill.

1 14. The method as set forth in claim 1 wherein said model of a dental tool  
2 represents an amalgam carrier, said method further including the step of adding material  
3 to portions of said model of a tooth in the vicinity of said amalgam carrier.

1 15. The method for simulating dental procedures as set forth in claim 11 wherein  
2 said digital computer further includes means for storing volumetric object grid data  
3 specifying the attributes of at least selected ones of said volume elements.

1 16. The method for simulating dental procedures as set forth in claim 14 further  
2 including the step of responding the movement of said model of a dental tool with respect  
3 to said model of a tooth by modifying said volumetric object grid data.

1 17. The method for simulating dental procedures as set forth in claim 15 further

2 including the step of responding the movement of said model of a dental tool with respect  
3 to said model of a tooth by modifying said volumetric object grid data and said data  
4 specifying the attributes of at least selected ones of said volume elements.

1 18. The method for simulating dental procedures as set forth in claim 17 wherein  
2 said digital computer further includes means for storing data for representing the shape  
3 and character of a modification region of said model of a dental tool to control the  
4 manner in which said volumetric object grid data is modified.

1 19. Apparatus for simulating dental procedures for training a dental student  
2 comprising, in combination, a digital computer consisting of at least a processor, a  
3 display device, a haptic interface including a moveable stylus manipulatable by said  
4 student, and storage means for storing:  
5 volumetric object grid data for representing a tooth as a collection of volume elements  
6 in three-dimensional space,  
7 tool definition data for representing the shape and character of a modification region of  
8 a dental tool in three-dimensional space, and  
9 a simulation program executable by said processor in response to the movement of said  
10 stylus for moving a displayed model of said dental tool with respect to a displayed model  
11 of said tooth to haptically simulate a dental procedure.

1 20. Apparatus as set forth in claim 19 wherein said storage means further stores  
2 attribute grid data specifying the attributes of at least selected ones of said volume  
3 elements.

1 21. Apparatus as set forth in claim 20 wherein said storage means further stores  
2 tool definition data specifying the characteristics of said dental tool.

1 22. Apparatus as set forth in claim 21 wherein said tool definition data specifies  
2 the shape and location of a modification region of said dental tool and wherein said  
3 simulation program includes means for modifying said object grid data for volume  
4 elements in the vicinity of said modification region.

1 23. Apparatus as set forth in claim 22 wherein said simulation program further  
2 includes means for modifying said attribute grid data describing volume elements in the  
3 vicinity of said modification region.

1 24. Apparatus as set forth in claim 23 wherein said tool definition data further  
2 includes the specification of the location of feel points relative to said modification  
3 region and wherein said simulation program includes means for controlling haptic forces  
4 applied to said stylus when said modification region of said dental tool is moved near to  
5 said tooth.

1 25. Apparatus as set forth in claim 24 wherein at least some of said feel points  
2 define the location of a handle portion of said dental tool.

1 26. Apparatus as set forth in claim 24 wherein at least some of said feel points  
2 are positioned outwardly from said modification region to increase the amount of force  
3 that the student must apply to said stylus to modify data representing said tooth

1 27. Apparatus as set forth in claim 24 wherein at least some of said feel points  
2 are positioned inwardly into said modification region to decrease the amount of force that  
3 the student must apply to said stylus to modify data representing said tooth.

1 28. Apparatus as set forth in claim 24 wherein as least some of said feel points  
2 are spaced from adjacent ones of said feel points by a distance larger than the dimension  
3 of projecting portions of said tooth thereby facilitating the removal of said projecting  
4 portions.

1 29. Apparatus as set forth in claim 24 wherein at least some of said feel points  
2 are positioned relative to said modification region to guide the movement of said  
3 modification region with respect to said model of a tooth.

1 30. Apparatus as set forth in claim 23 wherein said tool definition data further  
2 includes the specification of the location of one or more sensor points relative to said  
3 modification region for determining the attributes of volume elements of said tooth  
4 located at said sensor points.

1 31. Apparatus as set forth in claim 30 wherein said tool definition data includes the  
2 specification of the location of a single sensor point located substantially at the center of  
3 mass of said modification region.

1        32. Apparatus as set forth in claim 30 wherein said tool definition data further includes  
2        the specification of the location of one or more sensor points at or near the location of  
3        one or more selected ones of said feel points for determining the attributes of volume  
4        elements of said tooth at said sensor points.

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